Determining the parameters of the milling coulter of the sod seeder

Sergej Demshin[1], *Vasilij* Andreev[2], *Viktor* Saitov[1], *Maksim* Simonov[3*], and *Dmitrij* Zyryanov[1]

[1]Federal Agrarian Scientific Center of the North-East, 166 A, Lenin str., Kirov, 610007, Russian Federation
[2]Nizhniy Novgorod State Engineering-Economic University, 22 A, Oktyabrskaya str., Knyaginino, 606340, Russian Federation
[3]Vyatka State University, 36, Moskovskaya str., Kirov 610000, Russian Federation

Abstract. For strip sowing of grass seeds into the sod, a milling coulter with bladed knives has been developed. To determine the optimal parameters and modes of operation of the milling coulter with lamellar knives, a three-level Box-Benkin plan for three factors was implemented. Regression models of the developed milling working body are obtained. An increase in the peripheral speed of the knives of the milling working body significantly improves the quality of tillage, regardless of the number of knives. An increase in the number of knives of the milling coulter also causes an increase in the content of soil particles of 0...25 mm, and the transition from two knives to four ensures its increase by 15.6...20.8%, moreover, the replacement of four knives with six knives - only by 5.8...7.3%. The minimum energy consumption of the milling working body with six bladed knives is 2.0…2.2 kW, which was obtained at a peripheral speed of the knives of 6.0…6.4 m/s. The maximum content of soil fractions 0…10 mm and 0…25 mm, respectively, 69.8% and 91.8%, provides a milling coulter with lamellar knives at their peripheral speed of 8.0…8.4 m/s.

1 Introduction

Providing the livestock sector of the agro-industrial complex of Russia with a sufficient amount of high-quality feed depends on the use of biologically and economically sound methods of grassland management. In fodder production both in our country and in foreign countries, minimal tillage technologies are widely used, in which seeds are sown in uncultivated soil. Most technologies for improving forage lands are based on the chemical treatment of sod with herbicides or mechanical destruction of narrow strips of sod with subsequent sowing of grass seeds in the treated strip with special seeders or combined units [1-2].

Due to the high cost of chemical treatment and the negative impact on the environment, the most promising technology for minimal tillage is the strip sowing of grass seeds into the

* Corresponding author: simaksim@mail.ru

turf with mechanical destruction of the strip in it with the width necessary for favorable seed germination and seedling development [3-5].

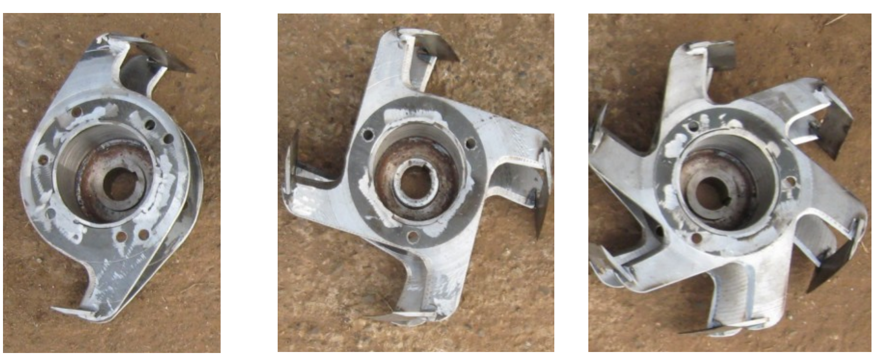
The technology of direct strip sowing of grass seeds into the sod using seeders with coulters in the form of disc cutters is very effective. At the same time, the costs of energy, seed, working time are significantly reduced, and it is also environmentally friendly. To apply this technology, a mounted sod seeder for strip sowing SDK-2.8, a semi-mounted SDKP-2.8 and a semi-trailed SDKP-2.8M were developed. These seeders ensure the sowing of grass seeds with the simultaneous application of the starting dose of mineral fertilizers [6-8].

2 Materials and methods

At the Kirov State Machine Testing Station, acceptance tests were carried out on seeders for direct sowing of grass seeds into the lawn SDK-2.8, SDKP-2.8 and SDKP-2.8M. Tests and operation of seeders SDKP-2.8 and SDKP-2.8M in production conditions have shown that, subject to agrotechnical requirements, they quite reliably perform the technological process, including milling a strip of sod, applying a starting dose of mineral fertilizers, sowing grass seeds and compacting the soil. At the same time, a number of shortcomings were identified related to the operation of disk cutters with L-shaped knives. In particular, the width of the strip formed by the disk cutter is not constant, since when the cutter is working, especially on strongly cohesive sod, L-shaped knives tear out pieces of sod from the edge of the strip, followed by their sliding into the cultivated soil, which worsens the quality of sowing. In addition, as the L-shaped knives wear out, the width of the processed strip decreases, and the press rollers move along the untreated surface.

The use of a double-disk milling coulter with L-shaped knives instead of single-disk cutters did not give a significant improvement in the quality of tillage. At the same time, the use of L-shaped knives, the cantilever mounting of which on the cutter disks causes their high metal consumption and complex shape, increases both the cost of the working body and the likelihood of breakage.

It is possible to eliminate the disadvantages inherent in milling working bodies with L-shaped knives by using a milling working body with lamellar knives (Figure 1).



a b c

Fig. 1. Milling working body with lamellar knives: a – number of knives $z = 2$; b – number of knives $z = 4$; c – number of knives $z = 6$.

This milling working body consists of two cut-out disks fixed on a nave. On the protrusions of the discs, bladed knives are installed with a grip width equal to the inter-disc distance and the outreach of the working part of the knife beyond the outer diameter of the disc, equal to the thickness of the soil chips [9].

To study the process of operation of the milling working body of a strip sowing planter when processing a strip in a sod monolith, a laboratory-field installationwas developed and manufactured for conducting experiments in the field (Figure 2).

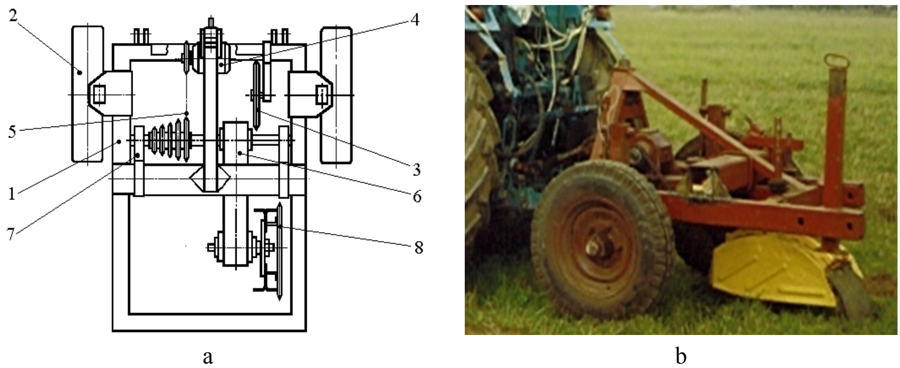


Fig. 2. Scheme of the laboratory-field installation (a) and general view of the laboratory-field installation in the course of research (b): 1 - frame; 2 - support wheel; 3 - disc knife; 4 - reducer; 5 - chain drive; 6 - drive; 7 - transmission shaft; 8 - milling working body.

The laboratory-field installation is made on the basis of the milling section of the sod seeder, mounted on a frame. It includes a frame 1 with support wheels 2, a transmission mechanism for transmitting torque from the electric motor or from the tractor power take-off shaft to the milling coulter 8. The coulter 8 is closed with a protective cover. The pressure of the milling working body on the soil is set by the compression of the spring (not shown in the diagram). The depth of processing is regulated by changing the position of the supporting ski on the drive 6 relative to the drive housing. The kinematic scheme of the laboratory and field installation provides the rotational speed of the disc cutter from 290 to 1866 min^{-1} at the rotational speed of the tractor power take-off shaft of 540 and 1000 min^{-1}. The travelling speed of the installation depends on the speed of the tractor used as a traction device.

At the initial stage, comparative studies of the influence of the kinematic mode of the cutter on the quality of tillage with various types of openers were carried out: a double-disk opener with L-shaped knives, a serial disk cutter with L-shaped knives of the SDK-2.8 seeder and a milling working body with lamellar knives. The research results showed that, regardless of the kinematic mode of operation, the milling working body with bladed knives provides the highest quality soil crumbling and high stability of the width and depth of the processed strip in the sod monolith [10].

To determine the optimal parameters and modes of operation of the milling coulter with lamellar blades of the seeder for direct sowing into the sod, a three-level Box-Benkin plan was made for three factors. One of the main factors determining the process of soil milling is the travelling speed V_T of the unit, the peripheral speed V_O of the cutter. Their ratio affects the energy and technological indicators of the quality of work: the degree of crumbling of the soil, the crushing of the sod, and the stability of the operating modes [11].

The design of the milling working body with plate knives provides for the possibility of installing a different number of knives z. This necessitates the study of the influence of their quantity on the indicators of the quality of tillage and the energy intensity of the process.

Taking into account the results of preliminary studies, factors, levels and their intervals of variation were selected (Table 1).

The experiments were carried out on medium loamy soddy-podzolic soil with a hardness of 2.6 MPa and a moisture content of 17% in a soil layer of 0...10 cm.

Table 1. Designation, levels and intervals of variation of factors.

Code value of factors	Designation	Factor levels			Variation interval
		-1	0	+1	
x_1	Number of knives z, pcs.	2	4	6	2
x_2	Peripheral speed V_O, m/s	4.7	6.7	8.7	2
x_3	Travelling speed V_T, m/s	0.5	0.7	0.9	0.2

According to agrotechnical requirements, the structure of the treated soil should be finely cloddy with a predominance of lumps 3…10 mm in size, and the content of the soil fraction with particle sizes up to 25 mm should be at least 80%. In this regard, the following indicators were taken as optimization criteria: Y_1 – the content of the fraction of soil particles up to 25 mm, %; Y_2 – the content of the fraction of soil particles up to 10 mm, %; Y_3 – the content of the fraction of soil particles less than 3 mm, as potentially the most erosive particles, %. The fourth optimization criterion is the energy consumption of Y_4 sod milling, kW.

The experimental data were processed using the Microsoft Office XP and StatgraphicsPlus 5.1 software package.

3 Results and Discussion

After implementing the experimental plan and processing the experimental data, the following regression models were obtained that adequately describe real processes (tested by Fisher's F-criterion at a probability of p=0.95):

$$Y_1 = 82.1 + 11.88 \cdot x_1 + 7.91 \cdot x_2 - 0.77 \cdot x_3 - 4.5 \cdot x_1^2 - 1.8 \cdot x_1 x_2 + 0.57 \cdot x_1 x_3 - 3.91 \cdot x_2^2 + \\ + 0.37 \cdot x_2 \cdot x_3 - 0.83 x_3^2 \quad (1)$$

$$Y_2 = 60.8 + 16.66 \cdot x_1 + 7.26 \cdot x_2 - 0.67 \cdot x_3 - 9.55 \cdot x_1^2 - 2.55 \cdot x_1 \cdot x_2 + 1.58 \cdot x_1 x_3 - \\ - 3.85 \cdot x_2^2 - 1.33 \cdot x_3^2 \quad (2)$$

$$Y_3 = 30.05 + 0.85 \cdot x_1 + 3.96 \cdot x_2 - 1.17 \cdot x_3 + 2.03 \cdot x_1^2 + 2.09 \cdot x_1 \cdot x_2 + 3.28 \cdot x_1 x_3 - 5.03 \cdot x_2^2 \quad (3)$$

$$Y_4 = 2.98 + 0.4 \cdot x_1 + 0.19 \cdot x_2 + 0.2 \cdot x_3 - 1.34 \cdot x_1^2 + 0.09 \cdot x_1 \cdot x_2 - 0.08 \cdot x_1 \cdot x_3 + \\ + 0.42 \cdot x_2^2 + 0.14 \cdot x_2 \cdot x_3 + 0.14 \cdot x_3^2 \quad (4)$$

Analysis of the regression equations (1), (2) and (3) showed that an increase in peripheral speed V_O of the knives of the milling working body, regardless of their number z, increases the content of the soil fraction 0...25 mm (Figure 3) and 0…10 mm. With the number of knives z = 6 and peripheral speed V_O a little more than 8.0 m/s, the content of these fractions of soil particles reaches a maximum with a concomitant increase in the content of the soil fraction 0...3 mm. An increase in the number of knives z of the milling coulter also increases the content of soil particles 0...25 mm and 0...10 mm, and the transition from two knives to four provides an increase in the soil fraction 0...25 mm by 15.6...20.8%, and the replacement of four by six knives - only by 5.8...7.3%. A similar picture is observed for the soil fraction of 0…10 mm. This is due to the fact that an increase in the peripheral speed V_O and the number of knives z reduces the thickness of the chips cut off by the knife, and, as a result, a higher degree of soil crumbling is achieved.

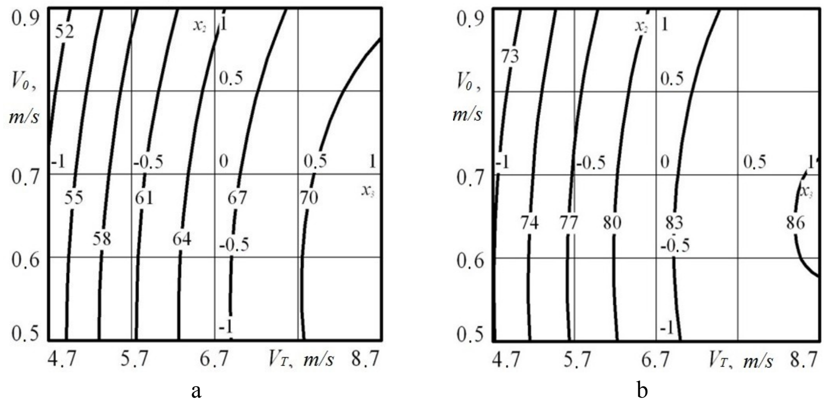


Fig. 3. Influence of peripheral speed V_O (x_2) of knives and travelling speed V_T (x_3) of the unit on the content of soil fraction 0...25 mm (Y_1) with a fixed number of knives z (x_1): a – number of knives z = 2 (x_1= – 1); b – number of knives z = 4 (x_1 = 0).

A change in the travelling speed V_T of the movement of the unit does not have a significant effect on the content of fractions of 0...25 mm and 0...10 mm of soil when the peripheral speed of the knives V_O is less than 6.0 m/s, regardless of their number. For higher values of the peripheral speed of the knives V_O, an increase in the speed of the travel of the seeder V_T somewhat reduces the content of these fractions. Moreover, for the milling working body with the maximum number of knives z = 6, this trend is observed to a lesser extent, since with a decrease in the travelling speed of the unit V_T, the thickness of the soil chips cut off by the knife is minimal. The analysis of the regression equation (4) was also carried out using the method of two-dimensional sections (Figure 4).

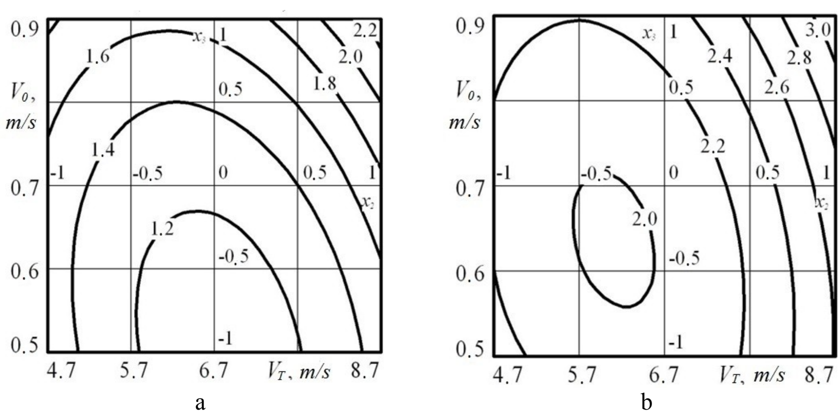


Fig. 4. Influence of peripheral speed V_O (x_2) of knives and speed of the travel V_T (x_3) of the seeder on the energy intensity N (Y_4) of the soil milling process with a fixed number of knives z (x_1): a – number of knives z = 2 (x_1 = – 1); b – number of knives z = 6 (x_1 = 1).

For the studied interval of the number of knives z = 2…6, there is an optimum point of the minimum energy intensity of the soil milling process, and its value corresponds to the interval of the peripheral speed of the knives V_O = 6.2…6.7 m/s and the speed of travel of the seeder V_T = 0.55…0.64 m/s. In this case, the power consumed by the milling working body with plate knives, when installing two knives, is N = 1.2 kW, and with six knives, N = 2.0 kW.

The maximum content of soil fractions of 0…10 mm and 0…25 mm, respectively, 69.8% and 91.8%, is provided by a milling coulter with lamellar knives at their peripheral speed V_O = 8.0…8.4 m/s. To reduce the energy intensity of milling, it is necessary to strive to reduce the number z of knives, the speed of travel V_T of the seeder and the peripheral speed V_O of the cutter knives, while at the same time taking into account that a decrease in the travelling speed V_T is undesirable due to a drop in the productivity of the sod seeder, and a decrease in the number z of knives entails a decrease tillage quality. Thus, the peripheral speed of the milling working body V_O with lamellar knives is the main factor in regulating the quality of tillage and the energy consumption of the cutter.

4 Conclusion

A milling working body with lamellar knives has been developed, the use of which provides better crumbling of the soil and high stability of the parameters of the milled strip in the sod compared to disk cutters with L-shaped knives. To determine the optimal parameters of the milling coulter, a three-level Box-Benkin plan was made for three factors. An analysis of the experimental results showed that an increase in the peripheral speed V_O of the milling coulter and the number of knives z significantly increases the degree of soil crumbling. The optimal values of energy consumption, equal to N = 2.0...2.2 kW, were obtained with a milling coulter with six bladed knives at peripheral speed V_O = 6.0...6.4 m/s. When choosing the number of knives, it is necessary to focus on creating optimal conditions for seed growth, which is characterized by the presence of a soil fraction of 0...10 mm, the maximum content of which, equal to 69.8%, was achieved at the peripheral speed of the cutter knives V_O = 8.0…8.4 m/s.

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